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ON THE

GEOLOGICAL FORMATIONS

OF

LAKE SUPERIOR.

By THOMAS MACFARLANE.

(From the Canadian Naturalist for May, 1867.*)*

The crystalline rocks of Lake Superior present many features of interest to the lithologist, and to the student of primary geology; and the sedimentary rocks of that region, being almost destitute of organic remains, have been the subject of much discussion among scientific men, which can, nevertheless, scarcely be said to have settled unequivocally the question of their age. Having, as I believe, observed certain new facts concerning the composition and association of these rocks, which are calculated to

throw some light on their origin and age, I have attempted to describe them in the following paper.

Four different formations are distinguishable on the north, south and east shores of the Lake, where I have had an opportunity of examining their constituent rocks and mutual relations, but the same formations may be observed elsewhere in this region. These formations have been designated as follows: The Laurentian system, the Huronian series, the Upper copper bearing rocks of Lake Superior and the St. Mary sandstones. The two first-named (and older) formations usually occupy those parts of the shores which form high promontories and precipitous cliffs, and they constitute, almost exclusively, the areas which have been explored in the interior. On the other hand, the Upper rocks and St. Mary sandstones are never found far inland, but occur close to the shore in comparatively low-lying land and rocks. They seem to have had, as the theatre of their eruption and deposition, the bottom of the Lake, at a time when its surface was at a higher level than it is at present, although not so high as the general surface of the surrounding Laurentian and Huronian hills.

I.—THE LAURENTIAN SYSTEM.

Under this name it has become usual, in Canada, to class those rocks which, in other countries, have been regarded as forming part of the primitive gneiss formation, of the primary or azoic rocks, or of certain granitic formations.

The most prevalent rocks of the Laurentian series on Lake Superior present a massive crystalline character, partaking much more of a granitic than of a gneissic nature. Some of these I shall endeavour to describe first. To the north of the east end of Michipicoten Island, on the mainland, there is a very large area of reddish-coloured granite, which exhibits, in a marked degree, the phenomena of divisional planes, and huge detached blocks. The rock is coarsely granular, has a specific gravity of 2·668 to 2·676, and consists of reddish orthoclase, a small quantity of a triclinic felspar, dark green mica (also in small quantity), and greyish white quartz. The mica is accompanied by a little epidote, and an occasional crystal of sphene may be detected. A few miles to the east of Dog River a grey granite occurs extensively, which does not show any divisional planes. The felspar of this variety is yellowish white, with dull fracture, and is fusible without difficulty. It is associated with black, easily fusible mica, in considerable quantity, and with quartz, which is occa-

sionally bluish tinted. The specific gravity of the rock is 2·750 to 2·763. Large-grained granite is of very frequent occurrence on Montreal River and on the coast betwixt it and Point-aux-Mines. It consists principally of orthoclase, in pieces from one to several inches in diameter, a comparatively small quantity of quartz, and a still smaller proportion of white mica. The promontory of Gros Cap, at the entrance of the Lake from River St. Mary's, is composed of coarse-grained and characteristic syenite. In some places its hornblende is soft, seems decomposed, and is accompanied by epidote. The rock is seldom free from quartz, and some of it contains so much as to be justly termed syenitic granite. A chloritic granite appears to occur at a few points on the north side of Bachewahnung Bay, and a small-grained granite, consisting exclusively of felspar and quartz, occurs in large masses at the north-western extremity of the same Bay. It has not the structure of granulite, and might be properly named aplite or granitelle.

These rocks are all unequivocally granular, without a trace of parallel structure. They far exceed in frequency and extent those which possess a thoroughly gneissic character; indeed, characteristic gneiss was only observed at Goulais Falls and at Point-aux-Mines. The rock of the latter locality varied from the closely foliated, resembling mica schist, to that of a granitic character. Granitic gneiss is found on the north shore of Bachewahnung Bay, between Chippewa River and Bachewahnung Village, on the road between the latter and the Bachewahnung Iron Mine, in the neighbourhood of the Begley Copper mine, and at other points on the north shore of Bachewahnung Bay.

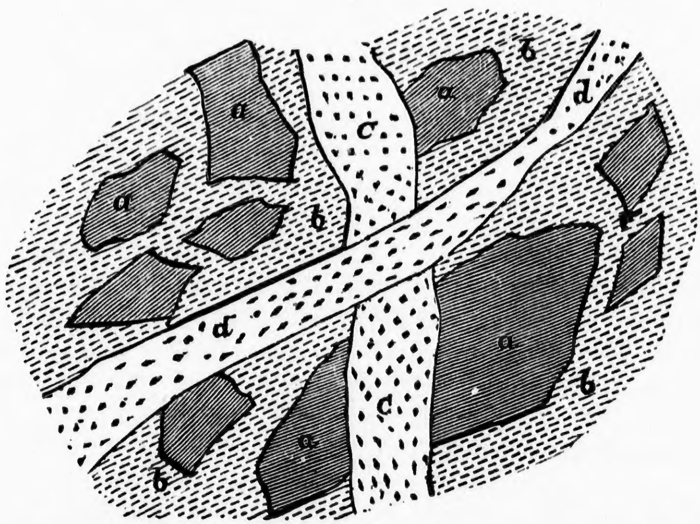
Almost equal in frequency to these thoroughly granitic and gneissic rocks, there are found certain aggregates of rocks which present different lithological aspects almost at every step, and which can only be generally described as brecciated and intrusive gneissic, granitic, or syenitic rocks. There is, however, to be detected a certain uniformity in the manner of their association with each other, which is of the greatest interest, and several instances of which it is now proposed to refer to. On the north shore of the Lake, about twenty-five miles west of Michipicoten Harbour, one of these rock-aggregates may be observed. Here fragments of a dark schistose rock, consisting of felspar and hornblende (the latter largely preponderating), are enclosed in a coarse-grained syenitic granite, and both are cut by veins of

another granite containing much less hornblende than the second-mentioned rock. These veins are, in their turn, intersected by a vein of fine-grained granite, consisting of quartz and felspar, with traces only of mica or hornblende. The specific gravities of these different rocks were found to be as follows:—

Hornblendic schist........................	2·836
Syenitic granite................................	2·787
Granite..	2·608
Fine-grained granite..........................	2·630

That the specific gravity of the last-mentioned rock should be greater than the one preceding, is attributable to its containing more quartz. Figure 1 gives a representation of the phenomena here observed. No chemical analysis of these rocks is required to

Fig. 1.

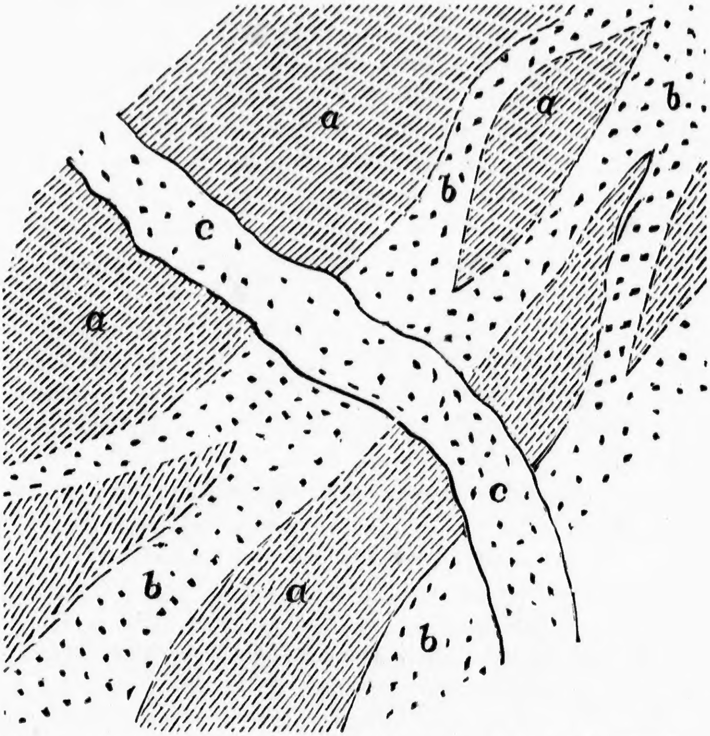


a. Fragments of hornblendic schist. | *c.* First intersecting granite.
b. Enclosing syentic granite. | *d.* Second intersecting granite.

show that the newer they are the greater are their contents in silica. This is evident as well from their specific gravities as from their mineralogical composition. The following relations, similar to these are observable on the north side of the Montreal River, at its mouth. The prevailing rock here is small-grained granitic gneiss, which contains lighter and darker coloured portions, according as the black mica which it contains is present in smaller or larger quantity. A triclinic felspar is also noticeable in it. Pieces of this rock are seen to be cut off and enveloped in a

finer-grained granite, of a much lighter colour than the gneiss, and comparatively poor in the black mica. The specific gravity of the gneiss is 2·667, and that of the granite, 2·648. Veins of large-grained granite, containing very little mica, traverse both of the rocks just mentioned. The appearance of these rocks is shewn in Figure 2. At the falls of the Chippewa or

Fig. 2.



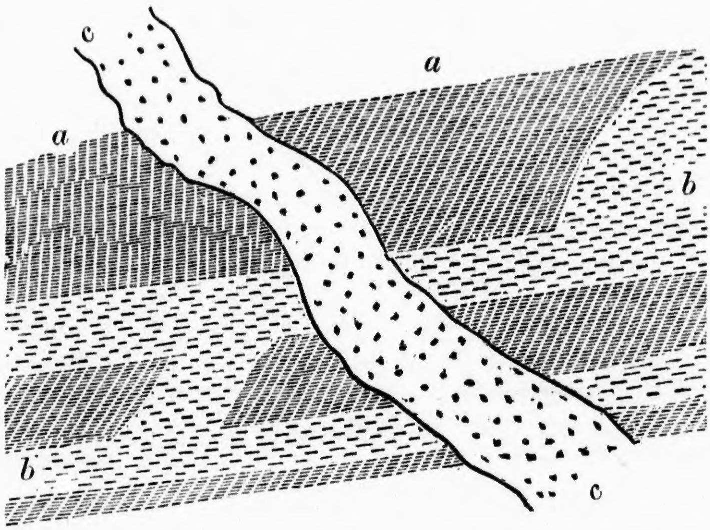
a. Granitic gneiss. | *b*. Fine-grained granite. | *c*. Large-grained granite.

Harmony River, which empties into Bachewahnung Bay, the predominating rock is highly granitic gneiss, consisting of reddish orthoclase, quartz and dark-green mica. It is rather small-grained, and, when observed in mass, shows sometimes a schistose appearance, the direction of which ranges from N. 10° W. to N. 57° E. Occasionally, in the more micaceous portions, broad felspathic bands occur, with selvages rich in mica, forming the nearest approach to gneiss. The direction of these bands is altogether irregular. This is also the case with veins of large-grained granite which intersect the rock just described. This

granite consists mainly of red orthoclase, with a comparatively small quantity of quartz, with which a still smaller quantity of greenish mica is associated. The specific gravity of the granitic gneiss is 2·676, and that of the coarse-grained rock of the veins 2·594. On the north-east shore of the Bay, close to the landing place of the Begley Mine, rocks are observed consisting principally of granitic gneiss, in hand specimens of which, no parallel structure can be detected. At some places, however, in larger masses, a schistose appearance is observable, with a strike of N. 75° E. This rock, which is syenitic, contains masses and contorted fragments of gneiss very rich in hornblende. Both the fragments and enclosing rock are intersected by veins of large-grained granite, containing little or no hornblende or mica. In the most south-easterly corner of Bachewahnung Bay, rocks occur, which, although they are totally devoid of any approach to gneissic structure, and possess a very different composition, bear some resemblance in the manner of their association to those just described. A dark-coloured, small-grained mixture of felspar and greenish-black mica, with occasional crystals of reddish orthoclase, and, more rarely, of greenish-white oligoclase, is enclosed in and intersected by another rock consisting of a coarsely granular mixture of orthoclase and soft dark-green mica, enclosing crystal of orthoclase (but no oligoclase) from one-quarter to three-quarters of an inch in diameter. Both of the rocks might be called micaceous syenites, but as they possess a pdelorphyritic structure, they probably belong to the rock species called minette. The matrix of the first-mentioned and darkest coloured rock is fusible, but the orthoclase which it encloses is less readily so. In both rocks, where exposed to the action of the waters of the Bay, the micaceous constituent has been worn away, and the grains and crystals of orthoclase project from the mass of the rock The specific gravity of the small-grained rock is 2·85, and that of the coarse-grained enclosing rock 2·65. They are both intersected by narrow veins of granite, consisting of felspar and quartz only, the specific gravity of which is 2.62. At Goulais Falls, about fifty miles up the Goulais River, gneiss occurs, which is very distinctly schistose, contains a considerable quantity—about one-third—of brownish black mica, interlaminated with quartzo-felspathic layers, in which a transparent triclinic felspar is observable. The gneiss possesses a specific gravity of 2·74 to 2·76. Its strike and dip are variable; the former seems, however, to average N. 55° E.,

and the latter varies from 14° to 26° north-westward. It is interstratified with a small-grained granitic gneiss, containing much less mica than the last—about one-twentieth only,—no triclinic felspar, and having a specific gravity of 2·71 to 2·72. The same granitic gneiss intersects the characteristic gneiss in veins, and both of these rocks are cut by a coarse-grained granite, almost destitute of mica, and completely so of schistose structure. The strata of the gneiss are much contorted in various places. The intersecting granitic gneiss and granite are almost equal in quantity to the gneiss itself; and although they occur as irregular veins, they are, at the point of junction, as firmly united with the gneiss as any two pieces of one and the same rock could well be. Figure 3 is intended to represent the relations observable at Goulais Falls. Between Goulais Falls and the

Fig. 3.

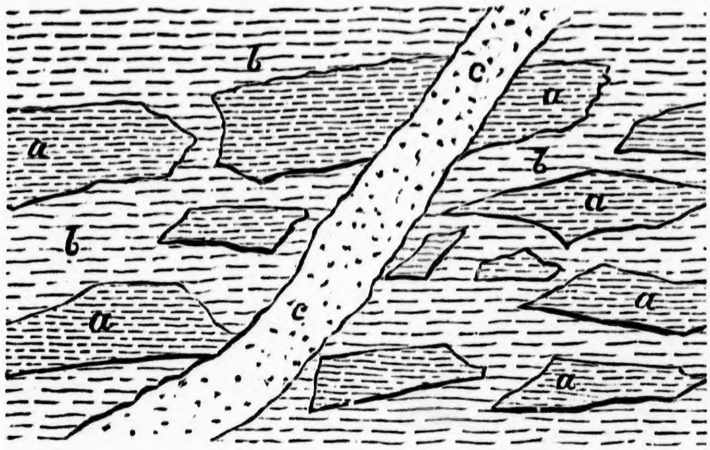


a. Gneiss. | *b*. Granitic gneiss. | *c*. Coarse-grained granite.

point where the line of junction between the Laurentian and Huronian rocks crosses Goulais River, there are numerous exposures of gneissoid rocks, but characteristic gneiss is of rare occurrence among them. At several places hornblende schist, in fragments, is observed enclosed in a gneissoid granite. Some of them are longer than others, and have their longer axes running N. 50° to 60° W. Hand specimens of the enclosing granite show little or no mark of foliation, but when seen in

place, a faint parallel structure is observable, the strike of which is N. 50° to 60° W. Both the hornblendic fragments and the gneissoid granite are cut by veins of newer granite. On the south-east shore of Goulais Bay, a beautiful group of syenitic rocks is exposed, the mutual relations of which are similar to those above described. Fragments of hornblende rock or schist, varying from half-an-inch to three feet in diameter, are enclosed in a coarse-grained syenitic granite, in which, occasionally, a rough parallelism of the hornblende individuals is observable, the direction of which is N. 57° E., and coincides with that of the longer axes of the hornblendic fragments. The specific gravity of the hornblendic rock is 2·94 to 3·06, and of the enclosing granite 2·74. Both are intersected by a coarse-grained granite, having a specific gravity of 2·61 only, and containing little or no hornblende or mica. The appearance here described are represented by Fig. 4.

Fig. 4.



a, Hornblende schist. *b*, Syenitic gneiss-granite. *c*, Coarse-grained granite

The mutual relations of these brecciated and intrusive rocks in eight different localities, some of them upwards of one hundred miles apart, have here been described, and it will be observed that, in every one of the instances mentioned, the oldest rock is the most basic in constitution, and this appears to be the case, without regard to the mineralogical composition or structure of the rocks associated together as above described. It matters not whether the older rocks be brecciated or entire, hornblendic or micaceous, granular, schistose or porphyritic, it is always most deficient in silica. It appears, further, that the newer the rock

which encloses or penetrates older ones, the more siliceous it becomes. On reference to the specific gravities above given of the various rocks, it might be supposed that their relations as to age might be equally well expressed by saying, the older the rock the heavier; the more recent, the lighter it is; and, in the majority of instances, this applies. But, as in the case of the rock-aggregate occurring to the west of Michipicoten Harbour, when we come to the very newest granitic veins, consisting only of orthoclase and quartz, those are the heaviest which contain most of the latter mineral, its mean specific gravity being 2·65, while that of orthoclase is only 2·55. It is to be remembered that these newest veins are altogether different in appearance from certain veins of large-grained granite, with distinct side joints, which are occasionally found intersecting these rocks, and the origin of which has been indicated by Dr. Hunt in his recent valuable report on mineral veins. Near Point-aux-Mines a vein of this nature is found, the rock of which is pegmatite, consisting of orthoclase, quartz, and greenish white mica, together with occasional grains of purple copper, copper pyrites, galena, and molybdenite.

It may not be out of place here to advance certain considerations regarding these Laurentian rocks, and especially concerning the peculiar rock aggregates just described. The relations of these rocks to each other we have seen to be as follows:—The older the rock the more basic is its nature, and the richer it becomes in triclinic felspar, hornblende, and mica. The newer the rock the more siliceous it becomes, and the more such minerals as orthoclase and quartz predominate. It can scarcely be supposed that this relation is an accidental one, for it is observable in every one of the instances above given, the localities of many of which are very far distant from each other. It would seem to be the consequence of an unvarying law which was in operation at the time when these rocks were first formed. At first sight, the facts above described would appear to militate against the idea of the igneous origin of these rocks, and, in fact, the relation is a similar one to that which has been observed among the constituent minerals of granite, and which is one of the chief difficulties in explaining the origin of that rock on the igneous hypothesis. In granite the quartz is frequently found filling up the interstices between the other minerals, and sometimes it even retains impressions of the shape of the latter. Nevertheless the felspar and mica are the most fusible, and the quartz the most infusible of

the constituents of granite. Similarly, the older basic rocks, among the brecciated and intrusive aggregates above described, are the most fusible, while the newer rocks, being most siliceous, are most infusible. At first sight, it is difficult to conceive how a basic and fusible rock could solidify from a melted mass previous to a more siliceous one. But the geological relations of these rocks are such as to afford the fullest proofs of their igneous origin. It may be urged that such an origin for the oldest and more basic fragments does not appear proved, but their similarity in mineralogical composition with the intrusive members of the aggregate is in favour of such a view. Furthermore, these older fragments shew, in every instance, such an analogy as regards their relation to the intrusive rocks that they cannot be regarded as accidental fragments of other rocks brought from a distance. If their origin were of this nature, they would not invariably be more basic in composition than the enclosing rock. The fact of their always bearing a certain relation, as regards composition, to the enclosing rock renders it unlikely that their source is similar to that of boulders in a conglomerate or fragments in a breccia. On the contrary, it would appear more reasonable to regard them as the first products of the solidification of the fluid mass from which the granites, and other rocks above described, resulted. In pursuing this subject further, it would appear not unreasonable to base some such theory as the following upon the facts above stated. The area now covered by these rocks must at one time have been occupied by a mass of fused silicates. The temperature of this fluid magma and of the surrounding crust has been intensely high, although perhaps very gradually on the decrease, and the extent of the igneously fluid material must have been such as to render uniformity in its chemical composition an impossibility. Variations in its composition, as well as in the manner of its solidification, may therefore be supposed to have obtained in different parts of the fluid area. According to th proportion of silica and bases present where crystallisation commenced and progressed, hornblendic rock, mica syenite, or comparatively basic granite, first assumed the solid form, leaving a part of the fluid or magma beneath or on the outside of it still in a plastic state, but changed in its chemical composition, and rendered more siliceous than the original magma. If the solidification commenced at a point where the fluid mass was comparatively undisturbed, the granular varieties of the rocks above described may have

been produced. If, on the other hand, the solidification took place while the fluid mass was in motion, the hornblendic and micaceous schists and gneisses were most probably the results of this process, and the strike of these would indicate the direction of the current at the time of their formation. The rarity or indistinctness of parallelism in the Laurentian rocks of Lake Superior shews, however, that no very constant and persistent motion in one direction took place in the fluid mass which produced them. This first solidification of part of the fluid magma most likely continued for a long period, and spread over a large surface; but there seems at last to have arrived a time when, from some cause or other, these first rocks became rent or broken up, and the crevices or interstices became filled with the still fluid and more siliceous material which existed beneath them. Gradually, this material solidified in the cracks, or in the spaces surrounding the fragments, and the whole became again a consolidated crust above a fluid mass of still more siliceous material. Further solidification of this latter material doubtless then took place, and continued until a second general movement of the solidified crust opened other and newer crevices, which became filled with the most siliceous material which we see constituting the newer veins among the rocks above described.

Although the theory here given as to the origin of these rock aggregates is in thorough harmony with the facts related concerning them, it is doubtless possible to urge objections against it founded upon the relative fusibility of their constituent rocks. There is no doubt that the point of temperature at which these various rocks become fluid under the influence of heat is higher with the newer than with the older rocks, but it does not follow that in cooling they solidify, that is, become quite hard and solid at the same point of temperature at which they fuse. Bischof describes an experiment which proves that the temperature at which certain substances solidify does not at all correspond with their fusing point. He prepared a flux, consisting of common glass and carbonate of potash, which fused at a temperature of 800° R., and melted it along with some metallic bismuth in a crucible. This metal fuses at 200°, and solidifies with a very uneven surface, on account of its tendency to crystallize. Although the difference between the fusing point of the bismuth and of the flux amounted to 600°, nevertheless, when the crucible cooled, all the irregularities of the surface of the metal were found to have

imprinted themselves upon the lower surface of the solidified flux, a very plain proof being thus furnished that at a temperature of 200° R., the flux was still soft enough to receive the impression of the solidifying metal. If we further observe the various fused slags which flow from different furnaces, we shall obtain some idea of the manner in which the rocks above described may have behaved during their solidification. The scoriæ of iron furnaces are usually very acid, containing as much as 60 per cent. of silica. They generally fuse at a temperature of 1450° C. As they flow out of the breast of the furnace, they may be observed to do so very leisurely, to be sluggish and viscid, but nevertheless to continue fluid a long time, and even in some cases to flow out of the building in which they have been produced, before solidifying. On the other hand, slags from certain copper furnaces, or from those used for puddling iron, are more or less basic, containing from 30 to 45 per cent. silica. As they flow out they are seen to be very fluid, and to run quickly, but they solidify much more rapidly than iron slags. Yet these basic slags fuse at about 1300° C., or about 150° less than the more acid slags. Those who have been accustomed to observe metallurgical processes will not find it difficult to conceive how a very siliceous slag might continue fluid at a temperature at which a more basic one might become solid. We conceive, however, that the rocks which we have described must have solidified under circumstances altogether different from those under which furnace slags cool. We suppose that these rocks must have solidified at temperatures not very far below their fusing points; that the temperature of the atmosphere, and of the fluid mass itself, had sunk somewhat beneath the fusing point of the more basic rocks before solidification began, and that at this point it was possible for the basic rocks to crystallize, while a more siliceous magma still remained plastic. This latter supposition does not appear unreasonable when the experiment above referred to, and the behavior of furnace slags above described, is taken into consideration.

It becomes a question of much interest as to whether these rocks are to be regarded as constituting one and the same, or several and distinct, geological formations. There cannot be a doubt as to the fact that some of them are of more recent origin than others; but, on the other hand, many of the veins above described do not present such distinct joints as are visible where trap or basalt dykes traverse sedimentary strata. Although the cementing material

of the brecciated rocks above described differs in composition from the fragments which it encloses, we nevertheless find that the two are usually so intimately combined with each other as to behave under the hammer like one and the same rock. There is, in the majority of cases, no joint to be found at their junction with each other; and in fracturing them, they very often break just as readily across as along the line which separates them. It would appear, therefore, that, although these rocks solidified at different times, the dates of their formation were not sufficiently far distant from each other to enable the previously existing rock to cool thoroughly before it became penetrated by or enclosed in the newer one; that consequently the older rock, being in an intensely heated condition, readily amalgamated at its edges with the next erupted and fused mass, and formed with it a solid compact whole. Apart from the difficulties which would doubtless attend any attempt to distinguish separate geological groups among these rocks, it would appear just as unreasonable so to separate them, as to regard each distinct stratum of sedimentary rock as distinct geological formations. According to Naumann, a geological formation consists of a series of widely extended or very numerous rocks or rock-members (*Gebirgs-glieder*), which form an independent whole, and are by their lithological and palæontological characters, as well as by their structure and stratigraphical succession (*Lagerungs folge*), recognisable as contemporaneous (geologically speaking) products of similar natural processes. According even to this definition, it would appear just to class all the rocks above described, in spite of the distinctly intrusive character of some of them, as belonging to one and the same geological formation,—in short, to the Laurentian series of Sir W. E. Logan, or the Primitive Gneiss formation of Naumann. The last-named geologist certainly distinguishes a separate granite formation, but the rocks included in it are generally more recent than the primitive gneiss or primitive schists. Where, as in Silesia, in Podolia on the Dnieper, in the central plateau of France, in Finland, in Scandinavia, and in the Western Islands of Scotland, granite occurs in similar intimate association with gneissoid rocks as on Lake Superior, Naumann always regards it as part and portion of the primitive gneiss. As early as 1826, Hisinger, in his work on Swedish mineralogy, shewed that the granite which occurs in intimate combination, by lithological transition and otherwise, with the primitive gneiss of Scandinavia, was of contemporaneous origin

with it; and in the Pyrenees, La Vendee, Auvergne, the Black Forest and Hungary, according to Coquand, Riviere, Rozet, Rengger, and Beudant respectively, the gneiss and granite of these countries cannot be separated into distinct formations, but form one and the same mass of primitive rock.

II.—THE HURONIAN SERIES.

The rocks of this system, as developed on Lake Superior, present at first sight rather a monotonous and uninteresting aspect to the student of lithology. Large areas are occupied by schistose and fine-grained rocks, the mineralogical composition of which is, in the most of cases, exceedingly indistinct. These rocks are, to a very large extent, pyroxenic greenstones and slates related to them. On closer examination, they are found to exhibit many interesting features, and it is possible to distinguish among them the following typical rocks:—

Diabase.—The granular varieties among these greenstones belong to this species. It is developed at several points on Goulais River, at some distance to the west of the Laurentian rocks already referred to. It is usually fine-grained, pyroxene is the preponderating constituent, and chlorite is present in considerable quantity in finely disseminated particles. The felspar is in minute grains, and, in many instances, it is only on the weathered surface of the rock that its presence can be recognized. One variety of this rock from the Goulais River has a specific gravity of 3·001. Its colour is dark green, and that of its powder light green. The latter, on ignition, lost 2·29 per cent. of its weight, and changed to a brown colour. On digestion with sulphuric acid, 22·99 per cent. of bases were dissolved from it, which circumstances would seem to indicate that the felspathic constituent is decomposable by acids, and is therefore, in all likelihood, labradorite. This rock is underlaid to the south-west by greenstone schist, striking N. 65° W., and dipping 75° north-eastward, and is overlaid by amygdaloidal diabase and greenstone slates, striking N. 66° W., and dipping 49° north-eastward. Granular diabase is also met with a few miles higher up the river from the rocks just mentioned, associated with porphyritic diabase and diabase schist, the latter striking N. 55° to 65° W., and dipping 60° north-eastward. Similar rocks were observed on the hills between Bachewahnung and Goulais Bay, and at several points on the north shore of the lake between Michipicoten

Harbour and Island. In the neighbourhood of, and on the road to, the Bachewahnung Iron Mine, they are also plentiful. Not unfrequently the pyroxene in them assumes the appearance of diallage.

Augitéporphyry.—The porphyritic diabase above referred to is a small-grained diabase, in which are disseminated crystals of pyroxene, about three-eighths of an inch in diameter. The specific gravity of the rock is 2·906. Its fine powder has a light greenish grey colour, which changes on ignition to dark brown, 2.01 per cent. of loss being at the same time sustained. Hydrochloric acid dissolves from it 23·48 per cent. of bases.

Calcareous Diabase.—The amygdaloidal diabase above mentioned is the same rock as is termed by Naumann *Kalkdiabase.* It is a fine-grained diabase, somewhat schistose, in which oval-shaped concretions of granular calcspar occur. The latter are not, however, always sharply separated from the mass of rock, which is slightly calcareous. The amygdules, if such they can be called, have their longer axis invariably parallel with each other, and with the schistose structure of the rock.

Diabase Schist.—This rock occurs much more frequently than either of those just described. It is, indeed, difficult to find a diabase among these Huronian rocks which does not exhibit a tendency to parallel structure, or which does not graduate into diabase schist. But the latter rock occupies considerable areas by itself, not only on Goulais River, but also on that part of the north shore referred to in this paper. The higher hills to the north-east of Goulais Bay consist, to a large extent, of this rock. Apart from its schistose structure, it possesses the characters of diabase. For example, a specimen of the rock from the north shore has a specific gravity of 2·985. Its powder, which is light grey, changes on ignition to light brown, losing 1·43 per cent. of its weight. On digestion with hydrochloric acid, it loses 14·24 per cent. of bases; and with sulphuric acid, 16·12 per cent. It is fusible before the blow-pipe. Many of these schists are pyritiferous and calcareous, and these graduate frequently into greenstone slate.

Greenstone and Greenstone Slate.—The rocks above mentioned, being small-grained, are recognizable without much difficulty; but, besides these, and occupying much more extensive areas, there occurs finely granular and schistose rocks, many of them doubtless of similar composition to the above mentioned diabase and diabase schist. Where the transition is traceable from the

latter rocks to those of a finer grain, the same names are perhaps applicable. But since this is not always the case, it would seem advisable to make use of other terms for them until their composition is more accurately determined. The names aphanite and aphanite slate have been applied to rocks such as these, but since the former term has been applied by Cotta to compact melaphyre, it would seem better for the present to continue the use of the other terms, compact greenstone and greenstone slate, especially since the signification of the first of these has been so limited by Naumann as to denote pyroxenic greenstones only, thus distinguishing them from the hornblendic greenstones or Diorites. These pyroxenic greenstones, or fine-grained diabases, frequently contain more chlorite than the coarser-grained varieties. They are very frequent on the Goulais River, in the district between it and Bachewahnung Bay, and in the neighbourhood of the Bachewahnung Iron Mine. One specimen from a point four miles north-east of Goulais Bay yields 21·44 per cent. of bases to sulphuric acid. Its powder is dark green, changing on ignition to dark brown, and losing 1·72 per cent. of its weight. These greenstones are seldom destitute of iron pyrites. Quartz never occurs in them as a distinct constituent, and even in veins it is rare; but there are a few occurrences of greenstones which are lighter in colour, more siliceous, and harder than others, and which have possibly become so by contact with quartzose rocks. On the other hand, they are frequently found impregnated with calcareous matter. By assuming a schistose structure, these greenstones often graduate into greenstone slate, an apparently homogeneous rock, generally of a dark greenish grey colour and slaty texture. The latter character is sometimes so marked, that it becomes difficult to distinguish it from clay slate. The greenstone slates however, would seem to differ from the latter rock in the small quantity of water which they contain, their generally higher specific gravity, and in their yielding nothing which would form a good roofing slate. On the other hand, they are related to the greenstones and diabase schists not only by gradual transition, but in some of their physical characters. For instance, a greenstone slate from Dog River, on the north shore, of a dark grey colour, has a specific gravity of 2·738, and loses 1·62 per cent. of its weight on ignition, in which operation the colour of its powder changes from a greenish white to a decided brown. It yields to hydrochloric acid 16·44, and to sulphuric acid 10·29 of bases.

Siliceous Slate.—In many places bands of such dark coloured slate as that just described are interbedded with others which are lighter coloured and more siliceous. Such banded slates may, for instance, be observed on the north-east shore of Goulais Bay. Here the darker slate is very evenly foliated, of a dark greenish-grey colour, and has a specific gravity of 2·685. Its powder is light green, changing on ignition to light brown, and losing 2·02 per cent. of its weight. It yields to sulphuric acid 16·75 of bases. The rock of the lighter bands is highly siliceous, and in fusibility equal to orthoclase. The powder has a reddish grey colour, which changes on ignition to brownish grey, 0·54 per cent. of loss being at the same time sustained. Hot sulphuric acid removes only 3·79 per cent. of bases. A similar association of slates is found at a point bearing 41° 30' E. from the east end of Michipicoten Island. Here, a series of lighter and darker coloured bands of very decided slate occur, striking N. 78° to 86° W., and dipping 50° to 52° northward. They are overlaid by a band of dark green slate, which contains granitic pebbles, and this band is again overlaid by light coloured slates. Small bands may be observed to leave the dark green slates and to join with those of a lighter colour. The latter are not only lighter in colour, but harder and less dense, and occasionally show on their cleavage planes a silky lustre. A specimen gave a specific gravity of 2·681, and its powder, which was almost quite white, lost 1·12 per cent. on ignition, becoming slightly brown. It fuses only in fine splinters, and, generally, the fusibility of these slates is the greater the darker their colour.

Chlorite Schist.—Some of the greenstone slates occasionally contain an unusually large quantity of chlorite, and sometimes so much as to form chlorite schist. This schist forms the side rock of the Palmer Mine on Goulais Bay.

Quartzite.—This rock is of less frequent occurrence than I had anticipated. It is most frequent on the west and south-west side of the hills between Bachewahnung and Goulais Bay, and in the district north-eastwards from Sault Ste. Marie.

Hematite.—This mineral often occurs in such quantity as to constitute rock masses. It will however be referred to under the economic minerals of the series.

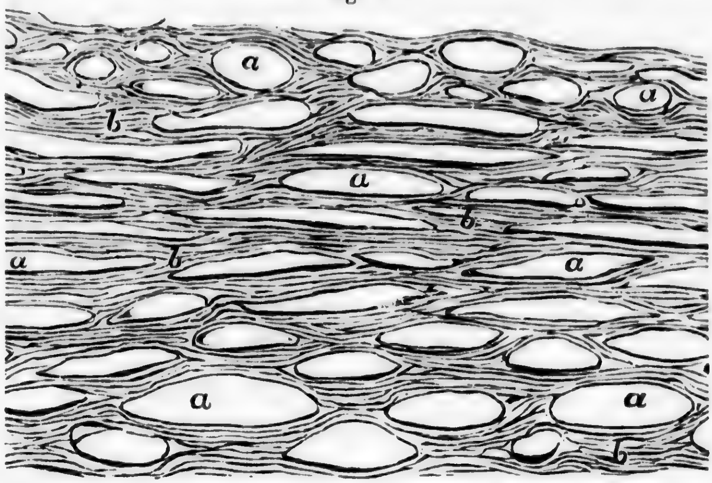
Greenstone Breccia.—The occurrence of angular fragments of other rocks in the greenstones above described is by no means rare, and the resulting breccias are common between Bachewahnung

and Goulais Bays. In the majority of nstances where the matrix is granular, the fragments are angular; on the other hand, where the matrix becomes schistose, the fragments are generelly rounded, and there results the slate conglomerate so characteristic of the Huronian series.

Slate Conglomerate.—This rock is extensively developed at the mouth of the Dore River, some distance to the west of Michipicoten Harbour. Its matrix is the greenstone slate above described. The boulders and pebbles which it encloses seem, for the most part, to be granite, and are rarely quite round in form. The most of them are oval or lenticular shaped, and then their outlines are scarcely so distinct as in the case of those which approach more closely to the round form. Very frequently those of a lenticular form are drawn or flattened out to such an extent that their thickness decreases to a quarter or half-an-inch, and they are sometimes scarcely distinguishable from the slate, except by their lighter colour. Part of the rock exhibits merely a succession of lighter and darker coloured bands, the former of which sometimes resemble in form the flattened pebbles above-mentioned. On account of the presence of these lighter bands, it is often impossible to select a piece which may be regarded as the real matrix of the rock. As in the case of some of the rocks above described, the light bands are more siliceous and less dense than the darker ones. The latter are, not unfrequently, calcareous. A specimen of this character had a density of 2·768 to 2·802. Its powder was light green, which changed on ignition to light brown, with a loss of 2·75 per cent. On treatment with sulphuric acid, it effervesced strongly, and experienced a loss of 36·85 per cent. Iron pyrites impregnates the matrix quite as frequently as calcareous matter. The direction of the lamination in the matrix is parallel with the longer axis of the lenticular pebbles, and where the boulders are large (they seldom exceed twelve inches in diameter) and round, the lamination of the slate winds round them, and resumes its normal direction after passing them. Occasionally a flattened pebble is seen bent half round another, and, among the very thin pebbles, twisted forms are not uncommon. The nature of the pebbles, especially of those which have been flattened, is sometimes very indistinct. The quartz is generally easily recognized in the larger boulders, but the felspar has lost its crystalline character, and the mica is changed into dark green indistinct grains, where it has not altogether disappeared. Besides the granitic pebbles,

there are others which seem to consist of quartzite. An idea of the structure of this rock is attempted to be given in figure 5.

Fig. 5.

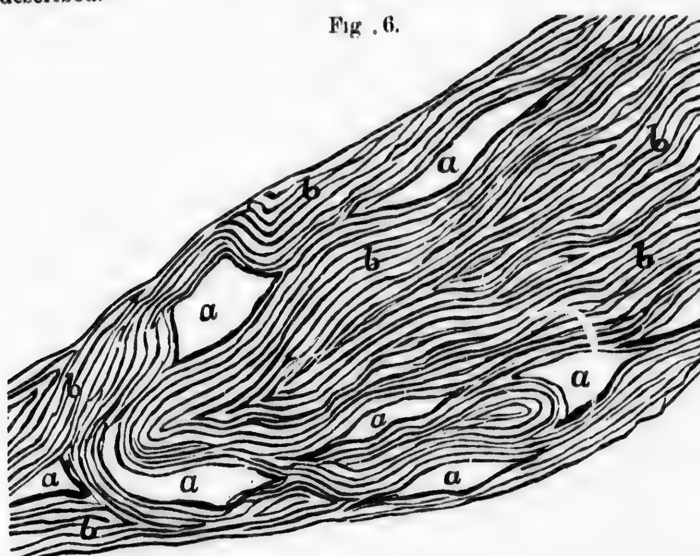


a. Granite boulders, and long drawn masses. *b*. Schistose matrix.

The manner in which these rocks are occasionally associated with each other is calculated, as in the case of the Laurentian rocks, to suggest to the observer some definite ideas regarding their origin. Equally instructive is the manner in which they adjoin the Laurentian areas at several points on the north shore, between Michipicoten Harbour and Island. I paid some attention to that point of junction which lies to the west of Eagle River, the precipitous cliffs to the east of which consist principally of diabase schist and greenstone slate. A few miles to the west of these cliffs, and at a point bearing N. 29° E. from the east end of Michipicoten Island, the Laurentian granite is penetrated by enormous dykes of dense basaltic greenstone (having the peculiar doleritic glitter when fractured), which contain fragments of granite. This greenstone is also seen in large masses, which can scarcely be called dykes, overlying the granite and enclosing huge masses of that rock, one of which I observed to be cut by a small vein of the greenstone. From this point to Eagle River those two rocks alternately occupy the space along the shore, seldom in such a manner as to show any regular superposition of the greenstone on the granite, but almost always more or less in conflict with each other. The greenstone, however, becomes more frequent towards the east, and at Eagle River it has almost wholly replaced the granite, and assumed a lighter colour and an irregular schistose

structure. The strike of these schists is, at places, quite inconstant; they wind in all directions, and what appear, at first sight, to be quartz veins, accompany their contortions. On closer inspection, however, of the largest of these, they are seen to be of granite, but whether twisted fragments of that rock or really veins of it, is, at first glance, very uncertain. Observed superficially, they have the appearance of veins, but they do not preserve a straight course, and bend with the windings of the enclosing schist. They often thin out to a small point and disappear, and, a few feet or inches further on in the direction of the strike, reappear and continue for a short distance. Sometimes a vein thins out at both ends and forms a piece of granitic material of a lenticular shape, always lying parallel with the lamination of the enclosing slate. Figure 6 is a representation of the phenomena here described.

Fig. 6.



a. Fragments and contorted pieces of granite.
b. Slates enclosing same.

At another point of junction, on the north shore, to the east of that above described, there is a large development of similar basaltic greenstone. Its constituents, with the exception of iron pyrites, are indistinguishable; it has a greenish black colour, and a specific gravity of 3. Its powder has a dark green colour, which changes on ignition to dark brown, with a loss of 1·79 per cent. of its weight. It yields to sulphuric acid 18·41 per cent. of bases.

It exhibits numerous divisional planes and a tendency to slaty structure, the direction of which is not, however, parallel with that of the divisional planes. It contains numerous fragments and long drawn contorted masses of granite, which are best discernible on the worn surface of the rock, and not readily so where it is freshly fractured. To the eastward it changes to a much harder light grey siliceous rock, having a specific gravity of 2·709 only. In fine powder this rock is white, but on ignition becomes brownish, and loses 0·55 per cent. of its weight. It yields only 4·62 per cent. of bases to sulphuric acid. At one place it seems to contain fragments and twisted pieces of the dark greenstone, and further eastward it assumes the character of a breccia, granite fragments being enclosed in the slaty rock, which is at some points darker, at others lighter, coloured. The fragments are sometimes quite angular, and sometimes rounded off, and not sharply separated from the matrix. Their longer dimensions are invariably parallel with the lamination of the matrix. The distance over which the transition extends renders it impossible to give any accurate sketch of the phenomena described.

Similar relations are observable at the junction of the two formations in the north-east corner of Bachewahnung Bay. Here the greenstone is compact, but still possesses the glittering basaltic fracture. The Laurentian rock is a highly granitic gneiss, and pieces of it are enclosed in the dark greenstone, which at one place seems to underlie the granite. A reddish grey felsitic rock, with conchoidal fracture, is observed at the point of junction. Eastward from it banded traps occur, striking N. 55° W., together with greenstone—breccia, and conglomerate. On ascending the hills behind this point another breccia is observed, of which the matrix is greenstone and the fragments granite.

With regard to the succession of these rocks, it will doubtless be found a matter of very great difficulty to establish any such, even if any order of superposition of a tolerably regular character should exist among them. That this is not very likely to be the case, will appear from the considerations yet to be advanced regarding the origin of these rocks. As to their general strike, it is scarcely possible to give any such, but within certain limits a tolerably constant strike may be observed. In the Huronian area, betwixt Goulais River and Bachewahnung Bay, although there are occasional north-easterly directions, the strike generally ranges from N. 40° to N. 80° W. On the north shore it is generally

east and west, seldom deviating more than 20° to the north or south of these points. The following observations were made in the neighbourhood of Eagle River, at points where the slates appeared most regular: N. 83° E., dip 45° northward; N. 80° W., dip 46° northward; N. 45° E., dip 34° north-westward.

In the foregoing description an attempt has been made to delineate with fidelity the most important features of the Huronian formation as developed on Lake Superior. It is now proposed to give a fair unstrained interpretation of the characters stamped upon the rocks of that series. The fact of the Laurentian granite being pierced, as above described, by Huronian rocks, and the fact of their enclosing fragments of such granite, proves incontestably that some of them are of eruptive origin, and of later age than the Laurentian series. The enclosure of the huge sharply angular fragments of granite in the very basic greenstone, above described, stands in intimate connection with the enclosure of smaller and contorted granite fragments in a matrix of similar chemical composition, but different (slaty structure. The appearances visible near Eagle River, of which figure 6 is an illustration, prove that enclosed granitic fragments sometimes undergo modifications of form through contact with certain Huronian rocks. In Foster and Whitney's Lake Superior Report (Part II., pp. 44 and 45), analogous phenomena are described, but the exactly opposite conclusion is arrived at, viz., that the granite is in the form of veins, and is the newest rock. There would seem to be only the two methods of explaining the facts described: either the granite forms veins penetrating the schistose greenstones, in which case the latter are the oldest rocks, or it is in the form of contorted fragments, in which case the enclosing rocks must be of eruptive origin. The fact that the granitic fragments do not cut but run parallel with the slates which enclose them, is the strongest argument against considering them to be veins. The supposition that they are long drawn and contorted fragments seems to be most in harmony with the facts stated, and with what is known as to the relative ages of the Laurentian and Huronian rocks. The true explanation most likely is, that the basic greenstone, after enveloping the granitic fragments, continued for some time in motion, and, previous to solidification, softened and rendered plastic the fragments, which then became drawn out in the direction of the flow of the igneous mass, and forced to accompany its sinuosities, and that the motion of the fluid mass previous to and during solidification developed in

the greenstone its schistose structure. The other facts, described above as observable at a considerable distance east of Eagle River, shew that something more than a mere modification of form is caused by the action of basic greenstone upon granite fragments. Not only are the latter there observed to be enclosed in, softened by, and twisted around with the greenstone, but the phenomena observed fully justify the supposition that they have been dissolved in it, that is to say, actually fused in and incorporated with its material. The fragments are seen to be firmly joined together with the enclosing rock, especially where the latter becomes more siliceous. Furthermore, their sharp angles are often rounded off, indicating plainly that these parts were first melted away by the fluid greenstone. Moreover, the product of the union of the latter with the dissolved parts of the granite is plainly visible. It is the siliceous slate rock described above as forming in places the matrix of the breccia. This siliceous rock, the specific gravity of which is much lower than that of the greenstone, is further seen to be twisted about with the latter in such a manner as, in its turn, to envelope parts of the greenstone, thus shewing that motion assisted the incorporation of the two. The reddish grey felsitic rock, mentioned as occurring at the junction of the two formations in the north-east corner of Bachewahnung Bay, has doubtless had a similar origin to that of this siliceous rock, and it is not unlikely that the banded traps and slates, so frequently found among Huronian rocks, are attributable to a similar mode of formation. Closely connected with the breccias just alluded to, so far as regards the cause of its peculiar structure, is the Huronian slate conglomerate. It is impossible to examine closely this rock without being impelled to the conclusion that its origin is not very different from that of the breccias; that its matrix has been a fused mass, flowing slowly but constantly in the one direction; and that its boulders are merely fragments which have been half melted and rounded off by contact with the igneous rock. The oval, twisted, lenticular and long drawn forms of the boulders are such as could never have been produced by ordinary attrition, and they frequently furnish examples of such intimate amalgamation with the matrix as are never found in aqueous conglomerates. Further, the fact of the boulders being frequently drawn out into what are simply bands of light coloured slate, not only disproves the sedimentary origin of the conglomerate, but indicates the manner in which the association of greenstone slate and siliceous slate

above described have been formed. They have simply been produced where no tumultuous motion was at hand thoroughly to incorporate the material of the greenstone with that derived from the softened fragments, but where a steady continuous motion, always in the one direction, drew out the materials of the different slates into long bands side by side with each other. It thus seems to us reasonable, and quite compatible with a scientific interpretation of the facts above given, to explain the origin of by far the greater number of the above enumerated Huronian rocks upon a purely igneous theory; and it has occurred to us that many of the instances of local metamorphism, recorded by geologists, in which the contact of an igneous rock caused the silicification or lamination of another, might be capable of thorough explanation in a manner similar to that in which we have tried to account for the origin of the breccias, conglomerates, siliceous greenstones and banded slates, which constitute such a large part of the Huronian series.

The Huronian series, whatever its mode of origin may have been, must undoubtedly be regarded as an independent geological formation. It has been represented as being "a mixture of the St. Alban's group of the upper Taconic with the Triassic rocks of Lake Superior, the trap native-copper bearing rocks of Point Keeweenaw, and the dioritic dyke containing the copper pyrites of Bruce mine on Lake Huron" * but surely such a description is based upon a misconception of Sir W. E. Logan's views on the subject. Until its discovery by Sir William, the Huronian formation was unknown to geologists as a separate and independent system, and even now it is only in comparatively few countries besides Canada that it has been shown to exist On a former occasion, in the columns of the *Naturalist* † I endeavoured to shew that the Azoic schists of Tellemarken, in Norway, were almost identical in lithological characters with the Huronian rocks, and Dr. J. J. Bigsby ‡ shortly afterwards insisted upon the fact of their being the same formations. Dr. Bigsby is of opinion that the Huronian also occurs on the Upper Loire, in France, and that it is a totally distinct formation from the Cambrian, with which it has hitherto been customary to associate it. The Huronian forms part of what Naumann calls the primitive slate formation.

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* Marcou; The Taconic and Lower Silurian Rocks of Vermont and Canada.

† Vol. vii, p. 113.

‡ Quart. Journ. Geol. Soc. Vol. xix, p. 49.

Besides the black and greenish black dykes which occur in the neighbourhood of, and stand in connection with, Huronian rocks, there are others which occur at a distance from Huronian areas, and whose rocks differ somewhat from those of that formation. This is the case, for instance, with a set of dykes which occur on the south-east shore of Goulais Bay, cutting Laurentian rocks. They are there separated from the gneissoid rocks by very distinct joints. They vary in thickness from nine to seventy feet, and strike N. 72° to 75° W. In the widest veins the rock is fine grained at the side and small grained in the centre, so that even there it is difficult to determine its constituents. They seem, however, to be dark green pyroxene and greyish felspar, with magnetic and minute grains of iron pyrites. The rock has a specific gravity of 2·974. Its powder, from which a magnet extracts magnetite, has a grey colour, which changes on ignition to a dirty brown, with a loss in weight of 1·67 per cent. Hydrochloric acid produces no effervescence, but removes 21·74 per cent. of bases. Sulphuric acid removes 20·83 per cent. The presence of magnetite and absence of chlorite would seem to indicate that the rock inclines more to the nature of dolerite than diabase. A similar vein of fine grained rock penetrates the syenite of Gros Cap, on the summit of that hill, striking N. 40° W. A very large mass of small grained doleritic rock likewise occurs at the mouth of the Montreal River, on its south bank. It probably forms a dyke of very large dimensions in the granitoid gneiss there. It consists, seemingly, of black augite, white or greyish white felspar (on some of the cleavage planes of which parallel striæ are distinctly observable), and magnetite. Its specific gravity is 3·090. Its powder yields magnetite to the magnet, and does not effervesce on treatment with sulphuric acid, which removes 11·15 per cent. of bases. Other dykes of this nature cut the reddish granite of the north shore opposite Michipicoten Island, and, nearer to Michipicoten Harbour, a sixty feet dyke of diorite cuts the grey granite. It is fine grained at the sides, but granular and even porphyritic in the centre. Its direction is N. 63° E. About a mile further east another dyke occurs, which seems to contain fragments of granite. Close to the landing place of the Begley Mine, in Bachewahnung Bay, a dioritic dyke, bearing N. 80° E., cuts gneissoid rocks. Further investigation is necessary to determine what relation, if any, these dykes bear to the Huronian series.

III. Upper Copper-bearing Series.

The name of the Upper Copper-bearing Rocks of Lake Superior was given to this series by Sir W. E. Logan, to distinguish it from the Huronian or Lower Copper-bearing Rocks. The geographical and geological position, lower altitude, regular bedding, and peculiar lithological character of these Upper Rocks cause them to be easily recognised and readily distinguished from the Huronian. They have been separated into an upper and lower group, the latter of which seems, however, to be confined to the north-west parts of the lake. Along its eastern shore, between Sault St. Marie and Michipicoten, there are frequently found, betwixt the water and the high Huronian or Laurentian hills, narrow strips or patches of the rocks of the upper group, which often jut out as small islands into the lake, and doubtless extend out great distances beneath its waters. Such limited strips of these rocks are found, for instance, skirting the base of Gros Cap, along the south shore of Bachewahnung Bay and at Cape Gargantua. But besides these and much more important for the study of the upper group of the Upper Copper-bearing series, there are occasional extensive developments of its rocks, many thousand feet in thickness, such as at Cape Mamainse, Michipicoten Island, and Point Keweenaw on the south shore. These rocks have been generally described in the Geology of Canada as sandstones, conglomerates, stratified traps and amygdaloids. In referring to them more minutely, the following rock-varieties may be distinguished as belonging to the upper group of the series :—

Granular Melaphyre.—A large number of the rocks of this series which have hitherto been described as traps and greenstones, belong to this species. The simplest variety of it is seen at the north-west end of Michipicoten Island, and consists of two minerals only, a felspar and a greenish black mineral. The felspar is the principal constituent, possesses a red, almost pink, colour, which it loses on ignition, and being readily fusible and but slightly decomposed by acids, is most probably oligoclase, or closely allied to that species in composition. The dark coloured mineral is easily fusible and has the appearance of augite. Some of it appears soft and decomposed, and has most probably been converted into delessite. These two minerals are combined into a small grained, distinctly compound rock, which does not effervesce with acids, and whose red colour is visible at a considerable

distance. It is very seldom however that this rock is observed with such a bright colour, or with constituents so distinctly separated. Much more frequently the felspar has a dark reddish-brown colour, and the grains of augite or delessite have a very indistinct contour. This is the case with some of the melaphyres of Mamainse and Gros Cap. When the brown coloured felspar predominates, and the augitic or chloritic constituent becomes scarcer and even more indistinct, rock-varieties are developed belonging to the species Porphyrite, hereafter to be described. When, on the other hand, the dark greenish constituent gains the upper hand, and is recognisable as consisting almost exclusively of delessite, it gives rise to the variety of melaphyre next described.

Delessitic Melaphyre.—This rock has a greenish-gray colour, and consists of a granular mixture of felspar and delessite, with small portions of magnetite and undecomposed augite. In some instances mica is also found as a constituent. The delessite, besides occurring in small grains, often forms larger rounded particles and amygdules, without however imparting to the rock a very marked amygdaloidal structure. The rocks enclosing the cupriferous beds of the Pewabic and Quincy Mines, and that from the Quincy adit are examples of this variety, and have already been described by me in this journal.* The delessite which enters so largely into their composition can scarcely have been one of the original constituents, and has probably resulted from the gradual alteration of augite, since authenticated instances are on record of the conversion of that mineral into delessite and green-earth. The specific gravity of these rocks varies from 2.83 to 2.89. When ignited they lose 1.32 to 3.09 per cent. of their weight, the powder changing from light greenish-grey to a light brown colour. Digested with hydrochloric acid from 32.44 to 35.72 per cent. of bases are removed from them, the greater part of which belongs to the chloritic constituent. While the variety of melaphyre first above described is seldom found with amygdaloidal structure, the delessitic melaphyres are exceedingly prone to be developed as amygdaloids. In this case the rock contains amygdules of small size but very numerous, and they are either filled with delessite alone, or are lined with a coating or rind of that mineral, in which latter case calcspar generally

* Vol. iii., Second Series, p. 2.

fills out the centre of the cavity. Quartz or agate is comparatively rare in amygdaloids the matrix of which is delessitic melaphyre.

Compact Melaphyre.—When the small grained melaphyres above described become so fine-grained as to render the recognition of their constituents impossible, there results the fine-grained traps which are so numerous on the south-west coast of Mamainse and on Michipicoten Island. These rocks vary from reddish, bluish, greenish, or greyish black, to decided black in colour, and possess not unfrequently conchoidal fracture and resinous lustre. Their specific gravities vary from 2.67 to 2.898, and they fuse before the blowpipe to glasses of black or brownish black colour. Occasionally their material becomes less homogeneous, and presents the appearance of an intimate mixture of reddish grey and green coloured specks, which may perhaps represent partially developed constituents. They exhibit various phenomena as regards divisional joints. Some possess a rudely columnar structure, others have planes of separation forming various angles with the plane of bedding, several shew a tendency to separate into flags, while a few instances are observable of curved shaly separation, (*Krummschaalige Absonderung*). Transitions can frequently be traced from these compact melaphyres to others approaching in character to porphyrite. For instance, to the west of the entrance to the harbour on the south side of Michipicoten Island, there is found, forming part of a bed of undoubted compact melaphyre, a rock of a greenish-grey colour, with conchoidal fracture. It had a specific gravity of 2.589, and could only be glazed at the edges before the blowpipe. To the east of the same harbour entrance, another rock occurs intermediate in character betwixt compact melaphyre and porphyrite. It is black, impalpable, with imperfectly conchoidal fracture. It bears some resemblance to pitchstone, but differs from that rock in its specific gravity, which is 2.774, and in being readibly fusible to a black glass. It possesses a slightly resinous lustre, and contains an occasional crystal of colourless triclinic felspar. It exhibits planes of separation at right angles, or nearly so with the inclination of the bed, and agate veins are observable, which seem to accompany the divisional joints. This latter phenomenon is also seen in some of the beds of compact melaphyre, and in one of these, curved joints are visible, standing at right angles to the plane of bedding and filled out with calcspar. Brecciated quartz veins occasionally permeate these rocks, and

agatic geodes are very frequent among them. The latter are sometimes so frequent as to form amygdaloids, but they are much larger, and never so numerous as are the cavities in the amygdaloids of which delessitic melaphyre is the matrix. There is further this peculiarity with the amygdules of the compact melaphyres, that they contain little or no delessite, agate occupying its place, with occasionally calcspar filling the centre of the geode.

Tufaceous Melaphyre.—Interstratified with the rocks above described, and much more frequently associating with, and graduating into the delessitic melaphyres than the other varieties, there are occasionally found beds of comparatively soft, dark brown, porous rock, with almost earthy fracture and seldom destitute of amydaloidal structure. These frequently carry metallic copper, and constitute the 'ash beds' so extensively worked in the mines of the south shore. Although they are generally of a dark brown or chocolate colour, as in the case of the 'Pewabic lode,' there are rocks of this species which are bluish-brown and green coloured. The matrix is generally fusible, and in places impregnated with grains of metallic copper, sometimes of a very minute size. The larger grains of the metal are frequently found in the amygdules, either alone or accompanied by green-earth, calcspar, quartz, delessite, laumontite, and prehnite. Besides the rounded grains or 'shot copper' of the amygdules, these rocks often contain huge masses of metallic copper, with which small quantities of native silver are associated. Large irregular patches and veins of calcspar, and smaller masses of epidote are frequently met with in these tufaceous melaphyres.

Porphyrite. -The transitions, which are frequently observable on the south side of Michipicoten Island, from compact melaphyre to porphyrite have been referred to above. Undoubted porphyrite is to be found at the south-west corner of the Island. It possesses a fine-grained greenish red matrix, containing small flesh-coloured crystals of felspar, some of which have striated cleavage planes. The specific gravity of the rock is 2.619, and the matrix is fusible at the edges. In the upper part of the bed the matrix of the rock becomes coarser grained, shewing distinctly felspar and a darker coloured mineral as constituents, with the small felspathic crystals still scattered through it. The felspar predominates in the matrix and determines the colour of the rock, which is dark red. Its specific gravity is 2.626, and it is fusible, although not readily, before the blow-pipe. It separates into blocks, with very

decided divisional planes, but of no regular form. Similar rocks are found at the south-east corner of the Island, where also rocks resembling pitchstone and pitchstone porphyry are extensively developed. The black shining impalpable trap, which has the appearance of pitchstone, has a specific gravity of 2.573. It is fusible to a brown glass, and sometimes contains small colourless felspar crystals. Where these accumulate, there results the rock resembling pitchstone porphyry. The crystals in this rock are frequently recognisable as triclinic. The matrix is fusible to a brown blebby glass, and the specific gravity of the rock as a whole is 2.631 to 2.678. Since the specific gravity of the rock in which no crystals occur is lower than that usually ascribed to melaphyre, and since it is greater than that of true pitchstone, it would appear reasonable to class both these rocks with the porphyrites, or with these porphyries which contain no quartz, to which they probably bear the same relation as true pitchstones bear to felsitic or quartzose porphyries.

Melaphyre Breccia.—Among the newest of the beds of compact melaphyre, developed on Michipicoten Island, there are sometimes observable beds of a breccia consisting of fragments of dark brown melaphyre, cemented together by a reddish-brown trappean sand. Occasionally the fragments appear rounded, and present more of the character of a conglomerate. Similar rocks are seen in the Point Keweenaw district.

Porphyritic Conglomerate.--At the south-west corner of Michipicoten Island there is visible a conglomerate bed, the boulders of which consist principally of porphyrite, in which a few minute felspar crystals are discernible. Some of the boulders are granitic, and occasionally pebbles occur consisting of or containing agate. These are enclosed in a matrix consisting of coarse-grained and red-coloured porphyritic or trappean debris. In the upper part of the Mamainse group similar conglomerates are found, but in one instance the matrix seems to consist of the same crystalline material as the boulders and fragments, and is very firmly cemented to these. The most interesting example of this rock is that of the Albany and Boston mine, near Portage Lake. Here the matrix of coarse-grained porphyritic sand is accompanied by calcspar, and in some places fine metallic copper.* Other porphyritic conglomerates occur to the south of Portage Lake, some of the boulders

* This Journal, Vol. iii., Second Series, p. 9.

of which consist of quartzose porphyry, and the matrix of some of which contains quartz as well as calcspar.

Felsite-tuff.—Overlying the Albany aud Boston conglomerate a bed of so-called 'fluckan' occurs, which is a fine-grained, dark-red shaly rock, in which pieces of a greenish blue colour are sometimes seen. Both substances are fusible before the blow-pipe, and contain occasionally small grains and flakes of copper.

Polygenous Conglomerate.—This name is applied by Naumann and Zirkel to those fragmentary rocks whose boulders consist of two or more different rocks. Conglomerates of this nature are especially frequent among the inferior rocks of the Mamainse group, and among those of Keweenaw Point. The boulders of these Mamainse conglomerates are chiefly of granite, gneiss, quartzite, greenstone, and slate, and some of the newer beds contain boulders of melaphyre and amygdaloid in abundance. The matrix is generally a dark red sandstone.

Sandstone. — Among the melaphyres and conglomerates of Mamainse and Point Keweenaw an occasional stratum of sandstone is found of the same character as that which forms the matrix of the polygenous conglomerates.

The manner in which the rocks above described are associated with each other, is much more regular than the architecture of the Laurentian and Huronian rocks. They are regularly interstratified with each other, and even among the melaphyres and porphyrites distinct bedding is observable. They do not seem to have been disturbed to such a degree as to occasion the formation of anticlinal and synclinal folds, and in each of the principal areas of distribution a tolerably persistent strike and dip can be observed.

The general strike of the rocks of the Mamainse group is N. 20° to 50° W., and the dip 20° to 45° south-westward. They are beautifully exposed along the west coast of Mamainse, and the highest strata of the group form the south-west extremity of the cape. The lower part of the group consists of granular and delessitic melaphyres, polygenous conglomerates and sandstone. In the upper part compact melaphyres and porphyritic conglomerates predominate. The total thickness of the group, according to an approximative measurement, is 16,208 feet, of which the conglomerates occupy 2,138 feet. The succession of the beds along the coast is quite regular; but on attempting to follow them inland, they are found to thin out and disappear, while others take their

places. This is especially the case with the conglomerates. Were the beds continuous throughout, the section above given ought to be repeated on the south coast, and round to Anse-aux-Crêpes. But there, although some of the melaphyre beds have the same strike and dip as on the west coast, there is not the same regularity, nor the same plentiful development of conglomerates. There are moreover evidences of great disturbances and of a conflict between the rock of some of the igneous beds and a sandstone, which here appears in highly contorted and sometimes vertical strata. On coming round the south coast of Mamainse, from Anse-aux-Crêpes, strata of sandstone are observed very much disturbed and dipping inland. As near as it can be ascertained, their strike is about N. 85° W., dip 25° to 40° northward. The sandstone is red coloured, and contains streaks and spots of a cream coloured felspathic substance, which also forms bands crossing the stratification. Many thin cracks filled with calcspar also traverse the beds. The same sandstone continues for about a hundred and forty yards further to the west, becoming still more disturbed, and containing between its layers the felspathic substance. The strike, where the beds are at all regular, is N. 10° W., and dip 52° eastward. Further west it changes to N. 52° E., with dip vertical, and in places 75° S. W. Here the sandstone becomes utterly broken up into a breccia, which has pieces from one inch to a foot in diameter invariably angular, and a matrix consisting of the white felspathic substance above mentioned, with occasionally calcspar. Further westward the measures are concealed for two hundred yards; then strata of bluish-grey calcareous sandstone are exposed, striking N. 40° E., and dipping 75° S. E. From this point for three hundred yards further north-westward, disturbed sandstone occupies the coast where the measures are not concealed. It is followed by a breccia similar to that already mentioned, with angular fragments of sandstone, and then by beds of trappean rocks, striking N. 75° W., and dipping 40° S. W. Rocks of this nature occupy the coast, where not concealed, for one and a half miles further north-westward. Here sandstone again becomes visible, in strata almost vertical, but nevertheless much bent. It is covered by a breccia consisting of sandstone fragments with a trappean matrix, and this again is surmounted by regular trap. In many places there would seem to be the clearest evidence that the trap lies unconformably upon the upturned and contorted edges of the sandstone. Besides the

breccia above mentioned, other rocks of a peculiar nature are found at the junction of the sandstone and trap. One of these is indistinguishable from quartzose porphyry, and another seems to consist of fragments of trap bound together by this same quartzose porphyry. There are good grounds for supposing that the latter rock is the product of the action of the more basic trap upon the sandstone, and results from the igneous amalgamation of the two rocks last named. These confused rocks occupy about a quarter of a mile of the coast. To the north-westward, although the sandstones occasionally protrude, they become much less frequent, while the overlying melaphyres become much more regular, and gradually assume the same strike and dip as the strata on the west coast. The hills to the north of Anse-aux-Crêpes consist of the same beds of melaphyre and conglomerate as were observed on the west coast, with similar strike and dip.

The eruptive origin of the melaphyres and traps of this group is evidenced not only by their crystalline character, and by some of their relations in contact with undoubted sedimentary rocks, but also by their occurring as intrusive masses in the gneiss of Point-aux-Mines, and in the granitoid gneiss of Chippewa Falls. At the latter place the melaphyre is in the form of a dyke, and at Point-aux-Mines it is seen to form a dome-shaped mass, completely surrounded by gnessiod rocks. Furthermore, the lower members of the Mamainse series are intersected by numerous dykes, consisting of compact melaphyre. In some of them, the constituents of that rock are distinguishable, but most of them are almost impalpable, vary from a reddish-brown to a dark green colour, and frequently exhibit at their sides bands of slightly different colours, which run parallel with the side-walls of the dyke.

The average strike of the Upper Copper-bearing rocks of Michipicoten Island is N. 68° E., and the dip 25° south-eastward. An approximative estimate of their thickness is as follows:—

Granular, delessitic and compact melaphyres, and conglomerates	10,000 feet.
Compact melaphyres with agate amygdules.	4,500 "
Resinous traps, porphyrites and breccias...	4,000 "
	18,500 feet.

If we compare the rocks of Michipicoten Island with those of Mamainse, it would appear that the inferior rocks of the latter group do not come to the surface at Michipicoten Island, and that

the higher rocks of the Michipicoten group have not been developed at Mamainse, or lie beneath the waters of the lake to the south-west of the promontory. It would therefore appear just, in estimating the thickness of the Upper Copper-bearing rocks of the eastern part of Lake Superior, to add to the Mamainse series the above mentioned 4000 feet of resinous traps or porphyrites, which would make the whole thickness at least 20,000 feet. The rocks of the west and south shores of Michipicoten Island present the most regular appearance, and it might be expected that those of the south shore would, from their strike and dip, repeat themselves on the east side. But, as in the case of Mamainse, such an expectation is disappointed. On examining the rocks of the east shore, the upper beds, consisting of the porphyrites above mentioned, seem regular enough, but beneath these come brecciated melaphyre, delessitic melaphyre cut by a porphyritic rock, and others in which the evidences of bedding are very indistinct. Among these rocks the two following may be particularised as occuring in large masses. The first has an impalpable flesh-red or reddish-grey matrix, wherein occur numerous grains of dark grey quartz, and also light-coloured soft particles, which seem liable to removal by atmospheric agencies, giving the rock where this has taken place a porous appearance. It also contains light red and ash-grey crystalline grains of felspar, and others which appear earthy and decomposed. The matrix is fusible, in fine splinters only, to a white enamel. The rock has an uneven fracture, a specific gravity of 2.493, and is probably a porphyritic quartz-trachyte. The other rock, which occupies a very considerable area, partakes more of the character of felsitic porphyry, although the felspar crystals are very often indistinct. It contains, besides these, numerous grains of greyish quartz, sometimes one-eighth of an inch in diameter, and a fine-grained, dark red, difficultly fusible, matrix. The specific gravities of three different specimens were found to be 2.548, 2.579, and 2.583. The bedding of the rock, if it possesses any, is very obscure; but it shews in places a tendency to separate into flags. It has a very rough uneven fracture, and is probably also quartzose trachyte. At the north-east corner of the Island it seems to overlie, unconformably, beds of trap, which here assume something like the ordinary strike and dip, viz., N. 72° E., dip 25° S. E.

The islands which lie opposite the mouth of the harbour on the

south shore are composed of a peculiar rock, which is nowhere visible on the main island. It consists of a reddish-brown impalpable matrix, with a hardness but slightly inferior to that of orthoclase, in which minute spots of a soft yellowish-white material are discernible. There are also lighter flesh-coloured grains observable, which seem to be incipient felspar crystals. The matrix is difficultly fusible to a colourless blebby glass, and the specific gravity of the whole rock, where freshly broken, is 2.469. A piece slightly bleached to a greyish-white, from its adjoining a crack in the rock, gave a specific gravity of 2.477. Some parts of it exhibit a slightly porous structure, but this was not the case with either of the pieces whose specific gravity were determined. The rock has a very uneven fracture, and is probably trachytic phonolite. The occurrence of these trachytic rocks on Michipicoten Island is very interesting, for they are the only ones of the region which have in other countries been found in connection with undoubted volcanoes.

The general strike of the strata of the rocks of Point Keweenaw, at least in the neighbourhood of Portage Lake is N. 30° to 40° E., and the dip 55° to 70° north-westward. The melaphyres predominate, although polygenous and porphyritic conglomerates are also frequent. The copper-bearing tufaceous melaphyres seem to be more plentiful here than in the other areas, or at least the mines to which they give rise are more extensively worked.

At the other points in the east shore of the lake, where rocks of the character of melaphyre have been observed, the area occupied by them is very limited, and confined to narrow strips of beach and rocky ground, between the lake and the much more elevated Laurentian or Huronian rocks. In the most westerly cove on the south shore of Bachewahnung Bay, red sandstone is observed striking N. 12° W., and dipping 15° south-westward. It is interstratified with conglomerate, the boulders of which are principally of quartzite, dark green slate and red-jasper conglomerate, which have doubtless been derived from the Huronian hills in the rear. They range in diameter from one to twelve and even eighteen inches. The matrix is generally red sandstone, but the interstices are sometimes filled out with quartz. A short distance along the shore to the north-east exposures occur of a reddish-brown melaphyre tuff, containing amygdules of calcspar and quartz, the matrix of which is very soft and decomposed.

The beds appear to strike N. 8° E., and dip 25° to 29° westward. They would therefore seem to be conformable with the sandstone and conglomerate. Further north-eastward the rock becomes more compact, of a reddish-green colour, and exhibits curves of igneous flow. The geodes become much less frequent and consist almost exclusively of agate. The next rock to the north-east is a light red sandstone, striking N. 65° W., and dipping 35° to 40° N. E. Its contact with the trap is not visible, but its dip is such as to lead to the supposition that it has been disturbed by that rock. There is a great thickness of this sandstone exposed here, in strata frequently vertical, striking generally east and west, or to the north of west, and exhibiting dips varying from 35° N. to 57° S., and at least two anticlinal axes. From what has been stated here and also concerning the south shore of Mamainse, it would appear that there is evidence of the existence of a sandstone of greater age than the bedded melaphyres and conglomerates, and it would appear not unreasonable to suppose that it belongs to what has been called the Lower group of the Upper Copper-bearing series.

The trap rocks which surround the south-west base of Gros Cap, although comparatively seldom amygdaloidal, are readily distinguished as melaphyres. They are sometimes coarse-grained, consisting of reddish-grey felspar, soft dark-green iron-chlorite (delessite), and occasional spots of yellowish-green epidote. From this they graduate into finer-grained varieties, but they very seldom become impalpable, or their constituents altogether indistinguishable. Sandstone was not observed in contact with the traps, but a large mass of quartzose porphyry is seen at a short distance from the shore.

Another large development of traps and sandstones occurs to the north of Pointe-aux-Mines, where an occasional bed of tufaceous melaphyre is also found.

Besides the rocks above described, there are found on the low ground betwixt Goulais and Bachewahnung Bays, betwixt the latter and Pancake Bay, and on many of the islands of the east shore, large areas of red sandstone, almost horizontal, which are supposed to be the continuation of that occurring at Sault St. Marie, and usually called the St. Peter Sandstone. The true relations of this rock to those of the upper group of the Upper Copper-bearing series have not yet been made out. It closely resembles, in lithological character, the sandstone described above as occurring in almost

vertical strata on the south shore of Bachewahnung Bay. The disturbance of the latter is reasonably attributable to the neighbouring melaphyres, in which case the sandstone would be the earlier rock. On the other hand, as Sir W. E. Logan observes, "the contrast between the general moderate dips of these sand- "stones and the higher inclination of the igneous strata at "Gargantua, Mamainse, and Gros Cap, combined with the fact "that the sandstones always keep to the lake side of these, while "none of the many dykes which cut the trappean strata, it is "believed, are known to intersect the sandstones (at any rate on "the Canadian side of the lake), seem to support the suspicion "that the sandstones may overlie unconformably those rocks "which, associated with the trap, constitute the copper-bearing "series."* The following facts are confirmatory of this view. In the bay immediately south of Point-aux-Mines, where the Mamainse series adjoins the Laurentian rocks, the lowest member of the former is unconformably overlaid by thin bedded bluish and yellowish-grey sandstones, striking N. 50° E., and dipping 18° north-westward. The lowest layer is a conglomerate, with granitic and trappean boulders, and a bluish, fine-grained and slaty matrix. It is about six feet thick, and is followed by thirty feet of the thin bedded sandstones, some parts of which might yield good flagstones. Some of the surfaces of these are very distinctly ripple-marked. Above these come thin, shaly, rapidly disintegrating layers, in which are found spheroidal concretions from five to ten inches in diameter. It is not possible to ascertain the total thickness of these sandstones, since they descend beneath the level of the lake. They are similar in lithological character to the sandstones which occur on the north side of Point-aux-Mines. Although there is no doubt that these sandstones unconformably overlie the melaphyre series, still their lithological characters are very different from those of the horizontal red sandstone above referred to. The latter is evenly small-grained, is coloured red by iron oxide, and contains here and there small pieces of red shale, which have evidently furnished the colouring matter. It frequently consists of evenly bedded red and yellowish-grey layers, and exhibits sometimes the phenomenon named by Naumann, discordant parallel-structure, and by Lyell, diagonal or cross stratification.

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* Geology of Canada, p. 85.

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In enquiring next as to what geological formation in Europe most closely resembles the Upper Copper-bearing series of Lake Superior, the opinion expressed by Delesse ought not to be lost sight of, viz., that the constituent minerals have the same meaning and importance for eruptive rocks which organic remains have for those of sedimentary origin. Therefore, where the palæontological evidence does not entirely contradict it, that derived from lithological resemblance ought to be allowed its full weight. The melaphyres of the upper rocks being interbedded with conglomerates and sandstones, the age of the latter may be ascertained approximatively by enquiring under what circumstances and during what period the melaphyres of Europe were developed. Upon this point Naumann thus expresses himself: "With regard " to the eruption-epochs of the melaphyres, there appears, indeed, " to have been many of them, but the most occur in the period " of the Rothliegende, or in the first half of the Permian forma- " tion, and all are probably more recent than the Carboniferous " system This applies at least to the melaphyres on the south " side of the Hundsrück, to those of the Thuringian Forest, of the " neighbourhood of the Hartz, of Lower Silesia, Bohemia, and " Saxony. Many of these melaphyres were deposited soon " after the commencement, others towards the end, of the " Rothliegende period, and generally the latter, in many coun- " tries, shews a decided coincidence, both as regards time " and space, with the formation of the melaphyres." Zirkel, in his recent work on "Petrographie," gives a description of the melaphyre deposits of Germany, of which the following is a translation: "In districts which are older than the " Carboniferous formation melaphyre rocks are but seldom found. " The melaphyres of the southern Hundsrück and of the Pfalz, " whose stratigraphical relations are better known than their " mineralogical composition, appear in the Carboniferous system " or the lower Rothliegende. This melaphyre region extends " from Düppenweiler to Kreuznach, a distance of twelve miles, " with a breadth between St. Wendel, Birkenfeld, Kirn, and " Grumbach of several miles. Very few irregular masses are known, " but, on the other hand, numerous veins have been observed with " thicknesses varying from four to sixty feet. They possess " mostly a vertical dip, cut sharply the Carboniferous strata, and " often extend on their strike considerable distances. The mass " of the vein frequently encloses fragments of the side rock, slate-

" clay or sandstone. But most frequently in this region, the " melaphyres present themselves in the form of beds, which are of " very variable dimensions, (often only five to ten feet, sometimes " two hundred feet thick,) and lie, for the most part, evenly " inserted between the strata of the Carboniferous system. Some " of these can be traced for a distance of two miles. Besides " these a melaphyre layer appears in this region, extending over " many square miles. It is superimposed upon the upper strata " of the Carboniferous system, and upon it rest the Conglomerates, " sandstones and slate-clays of the Rothliegende. This great " covering of melaphyre is at its edges accompanied by melaphyre-" tuffs, which are in many places developed as melaphyre-amygda-" loids. In very few instances only has it been observed that " these melaphyres have exerted altering influences upon the side-" rock. Within the limits of the Rothliegende melaphyres are very " frequent. According to Naumann the melaphyre of Ilfeld in " the Hartz, must be regarded as a thick layer bedded into the " Rothliegende. It nevertheless in places lies immediately over " the Carboniferous system, on account of its extending beyond " the edges of the lower strata of the Rothliegende. Naumann " also mentions a mass of melaphyre which in Tyrathal covers the " junction of the Greywacke with the Rothliegende, and in its " further extension overlies also the latter formation. The " melaphyre-amygdaloid of Planitz, near Zwickau in Saxony, " forms also a covering regularly inserted into the Rothliegende, " above its inferior strata. On the western declivity of the " Oberhohndorfer Hill, near Zwickau, the melaphyre which here " contains numerous green-earth and calcspar amygdules, shews an " interesting intercalation with the brownish-red slate-clays of the " Rothliegende, irregular lumps and patches of which being as it " were kneaded into the mass of the melaphyre. The melaphyric " rock of the Johann-Friedrich and Zabenstadter Adit, in Mansfeld, " is evenly interstratified in the Rothliegende. G. Leonhard " mentions that in the Rothliegende of the neighbourhood of " Darmstadt, at Gœtzenhain and Urberach, the melaphyre forms " distinct outbursts of considerable size in the form of domes " (*Kuppen*,) which consist in the centre of solid melaphyre, and " towards the periphery of amygdaloidal rocks, and shews in " places both flagstone-like and columnar separation. In Silesia " the melaphyres appear in two places: in the country between " Lœwenberg and Læhn, where they, according to the investi-

" gations of Beyrich, occur in several courses, striking from " north-west to south-east, intersecting the Rothliegende, and " in still more extended measure at the edge of the great " bay opening towards south-east in the Grauwacke at Landeshut, " in which the carboniferous formation and the Rothliegende " have been deposited, and in which they form, accordiug to Zobel " and Von Carnal, a range extending from Schatzlar to Neurode. " In north-eastern Bohemia, according to Emil Porth, and " Jokély, malaphyres are found as numerous, and sometimes very " thick layers, in the Rothliegende. Jokély describes, in the " district of Jicin, five beds of melaphyre in various parts of the " Rothliegende, which exhibit very distinctly observable strati- " graphical relations. They prove to be, for the most part, true " melaphyre streams, which have flown like lavas, and in visible " connection with undoubted vein-like outbursts. According to " Porth, the neighbourhood of the melaphyre veins is frequently, " for great distances round, a field of melaphyric ash and " scoriæ."*

From these quotations it is plain that, in Europe, melaphyres only made their appearance during the Carboniferous and Permian periods, and especially characterised the latter. The occurrence of porphyritic conglomerates in Germany is similarly limited. On this point Zirkel says: " As porphyritic eruptions principally fall " in the period of the Rothliegende, so the whole of the clastic " rocks of the porphyry family stand in close connection with the " deposition of its strata, to which they have also contributed a " considerable amount of material. For instance, coarse porphy- " ritic conglomerates form members of the Upper Rothliegende " in the Oschatz-Frohburg basin, in the Döhlen basin, at Wieser- " städt in the Hartz, and in the north-western part of Thüringia. " At Baden, in the Black Forest, the deepest strata of the " Rothliegende consist of porphyritic breccia and the middle " strata of conglomerates." † Even polygenous conglomerates, such as those above-mentioned, are especially frequent among the carboniferous and permian strata of Europe. Naumann thus briefly characterises the Rothliegende of Germany, which he considers as equivalent to the English lower New Red Sandstone and the French *grès rouge*: " The Rothliegende appears in so

* Zirkel; Petrographie. Vol. ii., p. 71.

† Zirkel; Petrographie. Vol. ii., p. 529.

" many of the countries of Germany, and in such great thickness, " that, in its mode of development there, we recognise the normal " type of this remarkable sandstone formation. The pigment of " the sandstone, consisting principally of iron-oxide, the frequent " occurrence of conglomerates, the often repeated change in the " size of grain of its rocks, the association with porphyries and " melaphyres, the very frequent layers of claystones and porphy- " ritic conglomerates, the great poverty, and often complete " absence of organic remains,—all these are characters by which " the Rothliegende is distinguished as quite a peculiar sandstone " formation."* That not one of the peculiarities here emphasised by Naumann are absent from the upper group of the Upper Copper-bearing rocks of Lake Superior, will be evident to any one who has observed them or carefully gone through the description above given. It therefore becomes a matter of much importance, and deserving of the most careful study, to ascertain whether this resemblance is a mere coincidence, or whether there is reason for supposing that any part of these Upper Copper-bearing rocks ~~are~~ of Permian age. is

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* Naumann; Lehrbuch der Geognosie. Vol. ii., p. 584.